<u>Our Case No. 56/423</u>

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTORS:

WALTER HUBER
UDO LINNEMANN
WOLFGANG HOLZAPFEL

TITLE:

POSITION MEASURING SYSTEM

ATTORNEY:

JOHN C. FREEMAN
BRINKS HOFER GILSON & LIONE
P.O. BOX 10395
CHICAGO, ILLINOIS 60610
(312) 321-4200

POSITION MEASURING SYSTEM

[0001] Applicants claim, under 35 U.S.C. §119, the benefit of priority of the filing date of January 31, 2003 of a German patent application, copy attached, Serial Number 103 03 795.0, filed on the aforementioned date, the entire contents of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a position measuring system comprising a scale and a scanning unit movable with respect to it.

Discussion of Related Art

[0003] As a rule, besides incremental signals regarding the relative offset of two parts that are movable with respect to each other, known position measuring systems provide also so-called reference pulse signals. With a defined relative position of the parts that are movable with respect to each other it is possible to provide an absolute reference of the position measurement by the reference pulse signals. Reference marking fields are arranged at one or several locations of the scale for generating the reference pulse signals. Inter alia, the scanning unit of the position measuring system includes at least one scanning plate with one or several scanning graduations by means of which it is possible to generate a reference pulse signal corresponding to the relative position of the scale and the scanning unit to be detected.

[0004] A number of options on the part of the scanning unit are known regarding the arrangement of the reference marking fields on the scale, or of the scanning graduations required for scanning the same.

[0005] For example, U.S. Patent No. 4,263,506, the entire contents of which are incorporated herein by reference, discloses the arrangement of the reference marking fields on the scale laterally adjoining the graduation track with the incremental graduation.

[0006] Besides this, it is also possible to integrate the reference marking fields at at least one reference position directly into the graduation track with the incremental

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graduation, such as is proposed, for example, in U.S. Patent No. 3,985,448, the entire contents of which are incorporated herein by reference. For example, one or several ridges or lines of the incremental graduation can be omitted at the desired location of the scale.

[0007] Further variations regarding the integration of reference marking fields into the track with the incremental graduation are known from DE 35 36 466 A1 and U.S. Patent No. 4,866,269, the entire contents of which are incorporated herein by reference. In these publications it is proposed to design the reference marking fields in the incremental graduation as aperiodic sequences of lines or ridges, or to use areas with changed optical properties differing from the remaining incremental graduation as reference marking fields.

[0008] In particular in the case of high-resolution optical position measuring systems, in which the scanning signals are generated based on the interference of superimposed partial beams of rays, there is the requirement in connection with the generation of reference pulse signals to also generate high- resolution reference pulse signals.

OBJECT AND SUMMARY OF THE INVENTION

[0009] It is therefore an object of the present invention to disclose a position measuring system by which the generation of high-resolution reference pulse signals is possible, besides the high-resolution incremental signals.

[0010] This object is attained by a position measuring system that includes a scale having an incremental graduation track of a defined incremental graduation period and on at least one defined reference position, a reference marking field with a mean reference marking graduation period, wherein the mean reference marking graduation period differs from the incremental graduation period. A scanning unit movable with respect to the scale, the scanning unit having a plurality of scanning elements for generating scanning signals, wherein at least two phase-shifted incremental signals are generated as scanning signals. A first evaluation device arranged downstream of the scanning unit that determines a rough reference position from a maximum of resultant disturbance with the scanning signals at a defined relative position of the

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scale and the scanning unit. A second evaluation device arranged downstream of the scanning unit that determines a beat signal phase from a difference between a whole-number multiple of a reference pulse signal phase and a whole-number multiple of an incremental signal phase. A third evaluation device arranged downstream of the first and second evaluation devices, which is suitable for unequivocally marking a beat signal period from the rough reference position and, if a defined phase position exists, to issue a fine reference position from the beat signal phase.

[0011] In accordance with the present invention, the determination of the reference position takes place in several steps. In the course of this, initially a rough reference position is determined by a first evaluation device from the maximum of the resulting disturbance in the scanning signals at a defined relative position of the scale and the scanning unit. The determination of a beat signal phase is performed by a second evaluation device from the difference between a whole-number multiple of the reference pulse signal phase and a whole-number multiple of the incremental signal phase. Finally, by a third evaluation device a high-resolution precision reference position is derived from the rough reference position and the beat signal phase.

[0012] Thus, one or several phase-shifted periodic scanning signals of high resolution can be detected through the steps in accordance with the present invention by detector arrays on the scanning side, which have a detectable disturbance in the area of the reference position. In accordance with the present invention it is possible to perform an additional high-resolution absolute position determination via the detection of the scanning signals which are disturbed with at this location.

[0013] The zero position, or reference position obtained from the reference pulse signals can be determined with a degree of accuracy sufficient for unequivocally marking an individual incremental signal period. Thus, the reproducibility of the position measuring system is put down to the reproducibility of the incremental position determination alone.

[0014] A number of options exist in regard to the concrete embodiment of the reference marking fields on the scale, as well as of the scanning plate in the scanning unit, i.e. as a result of the concrete scanning beam path.

[0015] It is therefore possible to integrate the scanned reference marking field into the incremental graduation track. Besides this, however, it is also possible to provide

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an arrangement of one or several suitably designed reference marking fields on the scale next to the incremental graduation track.

[0016] On the part of the detector, the detection of the resulting scanning signals can be provided in such a way that detector elements for the simultaneous detection of one or several phase- shifted scanning signals are provided, from which the incremental signal portions and the reference pulse signal portions then must be suitably separated. Alternatively to this it is also possible to provide separate detector elements for the detection of the different scanning signals in the form of incremental signals or reference pulse signals.

[0017] Moreover, several reference marking fields can be provided along the measuring path, which can then be provided at equal distances or can be distance-coded, etc.

[0018] Further advantages, as well as details of the present invention ensue from the following description of an exemplary embodiment by the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a schematic representation of the unfolded scanning beam path of an exemplary embodiment of a position measuring system in accordance with the present invention in accordance with the present invention;

[0020] FIG. 2 is a view from above of an embodiment of a scale of the position measuring system in FIG. 1 in accordance with the present invention;

[0021] FIGS. 3a to 3c are each representations for the explanation by example of the design of a reference marking field on the scale in accordance with the present invention;

[0022] FIG. 4 is a view from above of an embodiment of a scanning plate of the position measuring system in FIG. 1 in accordance with the present invention;

[0023] FIG. 5 is the representation of a single resulting scanning signal which can be generated by the position measuring system in FIG. 1;

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[0024] FIG. 6 is an example of a block circuit diagram to explain the generation in accordance with the present invention of a high-resolution reference pulse signal in accordance with the present invention; and

[0025] FIGS. 7a to 7e each show a signal diagram for explaining the block circuit diagram in FIG. 6.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] The unfolded scanning beam path of an exemplary embodiment of the position measuring system in accordance with the present invention is represented in schematic form in FIG. 1. It should already be pointed out here that alternative scanning configurations, or scanning beam paths exist besides the explained example, which can be realized within the scope of the present invention.

[0027] A so-called interferential multi-grating sensor will be explained in what follows by FIG. 1, on whose basis the present invention can be realized. In a known manner, the position measuring system includes, as components which are movable in relation to each other in the measuring direction x, a scale 10, as well as a scanning unit containing a number of scanning elements in a suitable, not represented housing for generating scanning signals. Here the scanning unit substantially includes a light source 21, at least one scanning plate 22 with one or several scanning graduations, as well as an opto-electronic detector array 23, only indicated schematically, which comprises one or several detector elements.

[0028] The unfolded scanning beam path of a variation of the position measuring system in accordance with the present invention operated in incident light is schematically represented in FIG. 1. This means that the beams S emitted by the light source 21 first impinge on the reflectively designed scale 10 and thereafter are propagated as spatially separated partial beams INC_{+1}, INC_{-1}, REF_{+1}, REF_{-1} in the direction of the scanning plate 22, or the scanning graduations arranged on it. In the case of the preferred incident light system this takes place by diffraction in the direction of the +/- 1st orders of diffraction at the scale 10. The partial beams INC_{+1}, INC_{-1}, REF_{+1}, REF_{-1} are again diffracted in the +/- 1st orders at the scanning plate 22, so that they are united again at the position x_{REF} at the scale 10. There they are again

diffracted in +/- 1st orders and are propagated as combined beams D in the direction of the detector array 23. The information regarding a resulting displacement of the scale 10 and the scanning unit is contained in the form of the partial beams which interfere with each other as a function of the displacement in the beam D, which is detected by the detector array 23. Among the information in the form of an intensity-modulated scanning signal which can be detected by the detector array 23 is information regarding the relative displacement, as well as in regard to an absolute position x_{REF}, along the measuring path. Therefore, in this exemplary embodiment the detection of the incremental signal, as well as the at least one reference pulse signal, takes place via the common detector array 23.

[0029] In principle it would also be possible within the scope of the present invention to employ separate detector arrays for detecting the incremental and reference pulse signals.

[0030] Customarily several phase-shifted scanning signals are generated in incremental position measuring systems, which are the further processed in a known manner. Further steps on the part of the scanning unit are required in regard to the beam D for generating the phase-shifted scanning signals, which are familiar to one skilled in the relevant art and therefore will not be further described here. In this connection, reference is made by way of amplification to WO 02/23131 of Applicant.

[0031] For reasons of improved representability, transmitting graduation structures on the part of the scale 10, as well as of the scanning plate 22, are represented without exception in FIG. 1. As already explained, in a preferred embodiment the scale 10 is embodied as a reflecting graduation structure in the form of a reflecting phase grating, i.e. in contrast to the representation in FIG. 1, only a single, twice-charged scale 10 is provided, which is reflectingly operated. Since in such a system partial beams are required, which are diffracted at the scanning plate 22 in the direction of the scale 10, in a possible variation the scanning plate 22 can also be designed to be reflecting. In a variation alternative to this, two scanning plates 22 are employed, which are used in incident light and are identically embodied, between which a suitable deflection prism is arranged, by which the deflection of the split beams in the direction toward the second scanning plate, or the scale 10 takes place. In the case of such a variation this is strictly speaking a four-grating sensor, wherein

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the first and fourth grating through which the light passes corresponds to the scale 10 used in reflection, and the second and third grating correspond to the respectively identically embodied scanning plates 22 between which the deflection prism is arranged. Regarding the last mentioned variation and further details of such a scanning beam path, reference is made here specifically to WO 02/23131 of Applicant.

[0032] The generation of the scanning signals, or of the incremental and reference pulse signals by the device in accordance with the present invention will be explained in detail in what follows by FIGS. 1 to 4. Each one of FIGS. 2 and 4 represents a greatly schematized view of the structures on the scale 10, or of the scanning plate 22 in FIG. 1.

[0033] A partial view from above on the scale 10 is represented in FIG. 2, in which the incremental graduation track is visible, which includes an incremental areas M_{INC} with a defined incremental graduation period TPM_{INC} and from whose scanning one or several incremental signals A, B, C result. A reference marking field M_{REF} is arranged at the definite predetermined reference position x_{REF} between two incremental areas M_{INC} and in this location is used for generating a reference pulse signal Z in order to provide in this way an unequivocal absolute reference during position determination.

[0034] Partial areas 11.1, 11.2 with different optical properties are arranged in the incremental areas M_{INC} periodically with the incremental graduation period TPM_{INC}. In the case where the scale is embodied as a reflection phase grating, these are for example alternatingly arranged partial areas 11.1, 11.2, which result in a different phase shift of the diffracted beams. In a possible embodiment, the incremental graduation period TPM_{INC} is, for example, $TPM_{INC} = 2$ μm. In a known manner, at least one high- resolution periodic incremental signal with the incremental signal period SP_{INC} results from the scanning of the incremental areas M_{INC}, such as has already been disclosed in the above mentioned WO 02/23131. Thus, in case of a selected incremental graduation period $TPM_{INC} = 2$ μm, the result is an incremental signal period $SP_{INC} = 0.5$ μm. Preferably two or more incremental signals are generated in this way, which have a defined phase offset with respect to each other, wherein in the case of two, or four, incremental signals, a phase offset of 90° results,

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while in the case of three incremental signals a phase offset of respectively 120° is provided.

[0035] In the present exemplary embodiment a reference marking field M_{REF} is arranged, directly integrated into the incremental graduation track, at the reference position x_{REF}, which also includes an arrangement, alternating in the measuring direction x, of partial areas with different optical properties. In accordance with the present invention, this graduation structure differs in a defined way from the periodic graduation structure in the incremental area M_{INC} in order to generate in this way a detectable reference pulse signal at this location. In a concrete embodiment, the extension d_{REF} of the reference marking field M_{REF} in the measuring direction x is typically $d_{REF} = 600$ µm.

[0036] The size, or design of the graduation structure in the reference marking field M_{REF} is now subject to certain considerations within the scope of the present invention. It is selected, or dimensioned in such a way that advantageously a graduation period is present in the area of the reference marking field M_{REF}, which will be called the mean reference marking graduation period $TPM_{REF,m}$ in what follows. In accordance with the present invention, the selection of the mean reference marking graduation period $TPM_{REF,m}$ takes place in such a way that it differs from the incremental graduation period TPM_{INC}, a concrete numerical example will follow in the course of the further description. Furthermore, in the present exemplary embodiment, the reference marking field has, besides the mean reference marking graduation period $TPM_{REF,m}$, a second periodicity, namely the periodicity of the incremental graduation period TPM_{INC}.

[0037] However, the provision of the two periodicities in this area is not important for the present invention, instead it was selected in the present exemplary embodiment because no separate detector elements for detecting the incremental signal and the reference pulse signal are provided. It is therefore desirable that an incremental signal with as little as possible disturbance is present in the area of the reference marking field, i.e. that in any case incremental position information is also available in this area. In principle it would be sufficient without this requirement to only provide the reference marking graduation period $TPM_{REF,m}$ differing from the incremental graduation period TPM_{INC} in the area of the reference marking field.

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[0038] In the present exemplary embodiment at least one periodic incremental signal results at the output of the scanning unit, which shows a disturbance in the area of the reference position x_{REF}, or in the area of the reference marking field M_{REF}, and which can be extracted from the periodic incremental signal(s) in the form of a high-resolution reference pulse signal.

[0039] Therefore, in this example different spatial deflection effects result for beams S impinging on the reference marking field M_{REF} in the spatial area of the reference marking field M_{REF} of the scale 10 because of the at least two different graduation periods TPM_{INC} and $TPM_{REF,m}$ which are present there. In a possible embodiment, the mean reference marking graduation period $TPM_{REF,m}$, for example, is selected to be slightly different from double the incremental graduation period TPM_{INC}. Moreover, in principle there are the most diverse other relationships between the different graduation periods TPM_{INC} and $TPM_{REF,m}$, provided that it is basically intended to provide more than only the reference marking graduation period $TPM_{REF,m}$ in the corresponding reference marking field M_{REF}.

[0040] In many cases, for separating the orders of diffraction of the incremental signal scanning beam path and of the reference pulse signal scanning beam path, it is possible to select a base periodicity, or mean reference marking graduation period $TPM_{REF,m}$ in the reference marking field M_{REF}, which clearly differs from the incremental graduation period TPM_{INC}. The periodicities are always determined in such a way that a beat signal portion of a beat signal period Λ results. The beat signal period Λ results here from the following equation:

$$1/\Lambda = \left| \ n/SP_{INC} - m/SP_{REF,m} \ \right| \qquad \text{(Equ. 1)}$$

wherein

SP_{INC} : incremental signal period

$SP_{REF,m}$: mean reference pulse signal period

$n, m = 1, 2 \dots$: n, m do not have a common divisor

[0041] The different periodicities SP_{INC}, $SP_{REF,m}$ are advantageously selected in such a way that the following applies to the resulting beat signal period Λ:

$$\Lambda = (5 - 100) * SP_{INC} \qquad \text{(Equ. 2)}$$

[0042] In a concrete example, meeting of this condition is assured with $TPM_{INC} =$ 2 µm (corresponds to $SP_{INC} = 0.5$ µm), $TPM_{REF,m} = 4.55$ µm (corresponds to $SP_{REF,m} =$ 1.1375 µm), n = 1, m = 2, from which a beat signal period $\Lambda = 4.1$ µm results.

[0043] The importance of the resulting beat signal for the present invention will be explained in detail in the further course of the specification.

[0044] A basic explanation will be provided in what follows by FIGS. 3a to 3c how, for example, the graduation structure in the area of the reference marking field M_{REF} can be dimensioned. Grating structures, still to be explained, including a sequence of ridges and gaps, are represented in each of FIGS. 3a to 3c in lateral views inclusive of the associated sine functions, which define the grating phase at the respective position, or the position of the ridge edges of the gratings.

[0045] FIG. 3a shows a first grating structure with a first graduation period which, for example, corresponds to the provided incremental graduation period TPM_{INC} on a scale.

[0046] A second grating structure with a second graduation period, which corresponds to a desired mean reference marking graduation period $TPM_{REF,m}$, is represented in FIG. 3b. In the present example the selection of the relationships of the reference marking and incremental graduation periods TPM_{INC}, $TPM_{REF,m}$ was made as explained above, i.e. the mean reference marking graduation period $TPM_{REF,m}$ is selected to be slightly different from double the incremental graduation period TPM_{INC}.

[0047] Finally, FIG. 3c shows the additive superimposition of the two grating structures in Figs, 3a and 3b. Accordingly, the superimposed structure contains the first, as well as the second graduation period TPM_{INC}, $TPM_{REF,m}$, respectively the

incremental graduation period TPM_{INC}, as well as the reference marking graduation period $TPM_{REF,m}$. Such a resulting grating structure can then be arranged in a reference marking field M_{REF} on the scale, as was explained above in FIG. 2. The grating structure in the adjacent incremental areas M_{INC} of the incremental graduation track is embodied in accordance with FIG. 3a.

[0048] This explanation of the principles for designing the reference marking field on the scale are of course to be understood as being by way of example. Therefore multiple alternative design options for the respective design of the reference marking field exist within the scope of the present invention.

[0049] It is possible to see in the basic representation in FIG. 1 what effects such a design of the graduation structure in the present exemplary embodiment in the area of the reference marking field M_{REF} has on the scanning beam path. Because of the existing at least two graduation periods TPM_{INC} and $TPM_{REF,m}$ in this area, splitting of the beam S coming from the direction of the light source 21 takes place into the partial beams INC_{+1}, INC_{-1}, REF_{+1}, REF_{-1}, which are further propagated in at least two different spatial directions +RR1, -RR1, +RR2, -RR2. In the present example, splitting of the incoming beam S into a total of four partial beams INC_{+1}, INC_{-1}, REF_{+1}, REF_{-1} results. In this case the partial beams INC_{+1}, INC_{-1} represent the +/- 1st order of diffraction of the incoming beam S, which were deflected into the spatial directions +RR1 and -RR1 because of the selected incremental graduation period TPM_{INC}, but the partial beams REF_{+1}, REF_{-1} represent the +/- 1st order of diffraction of the incoming beam S, which were deflected into the spatial directions +RR2 and -RR2 because of the selected incremental graduation period $TPM_{REF,m}$. While the partial beams INC_{+1}, INC_{-1} contribute to the generation of the at least one incremental signal on the scanning side, the partial beams REF_{+1}, REF_{-1} which only appear in the area of the reference marking field M_{REF} cause a definite disturbance with the incremental signal at this location, which can be extracted from the at least one incremental signal in the form of a reference pulse signal. Incidentally, in the concrete example the generation of three incremental signals occurs, which are phase-shifted by 120° from each other, called incremental signals A, B, C in what follows.

[0050]   Besides the explained steps on the part of the scale in the area of the reference marking field M_{REF}, certain steps are also required within the scope of the present invention on the part of the scanning unit and the scanning elements, i.e. in particular on the part of the scanning plate 22. As can also be seen in this connection in FIG. 1, the scanning plate 22 has at least one graduation structure which is embodied such that the partial beams INC_{+1}, INC_{-1}, REF_{+1}, REF_{-1} impinging on it from the different spatial directions +RR1, -RR1, +RR2, -RR2 are again reflected back to the scale 10 in the direction toward the reference marking filed M_{REF}. A beam D is then propagated from the scale 10 in the direction of the detector array 23. The displacement-dependent information regarding the incremental signals A, B, C, as well as the reference pulse signal in the form of the interfering partial beams INC_{+1}, INC_{-1}, REF_{+1}, REF_{-1}, are contained in the beam D, as explained above.

[0051]   FIG. 4 represents a view from above on an embodiment variation of a suitable scanning plate 22, which can be employed in a device with a scanning beam path in accordance with FIG. 1. As can be seen from the representation in FIG. 4, in this example the scanning plate 22 has scanning graduations in the form of incremental scanning gratings AG_{INC} and reference scanning gratings AG_{REF}, which are arranged spatially separated from each other. The various scanning gratings AG_{INC}, AG_{REF} again includes a sequence of partial areas with different optical properties, which are each alternatingly arranged in the measuring direction x. In the case of a scanning plate 22 employed in incident light, this can be, for example, a known incident light phase grating in which partial areas of different phase-shifting effects are alternatingly arranged.

[0052]   As can be seen in FIG. 1, the partial beams INC_{+1}, INC_{-1} being propagated away from the scale 10 in the area of the reference marking field M_{REF} therefore impinge on the two incremental scanning gratings AG_{INC} arranged on the exterior of the scanning plate 22. But the two partial beams REF_{+1}, REF_{-1} reach the two reference scanning gratings AG_{REF} arranged in the center. Each of the grating periods $TPAG_{INC}$, $TPAG_{REF}$ of the incremental scanning gratings AG_{INC} and the reference scanning gratings AG_{REF} have been selected, or matched to each other, in such a way that - as can be seen in FIG. 1 - a deflection of the partial beams from the various scanning grating area back in the direction of the reference marking field M_{REF} on the

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scale 10 takes place. In the concrete example in FIG. 4 this means that the incremental scanning grating graduation period $TPAG_{INC}$ is to be selected smaller than the reference scanning grating graduation period $TPAG_{REF}$ in order to meet the mentioned requirements.

[0053] Following the second diffraction of the partial beams at the scale 10, a recombined beam D results, which is propagated in the direction of the detector array and, in the various partial beams interfering with each other, contains information regarding the relative displacement, as well as in regard to a defined reference position x_{REF}. The detection of the resulting scanning signal takes place by the schematically indicated detector array 23.

[0054] The scanning signals resulting from such scanning in the area of the reference marking M_{REF} in the present example are represented in FIG. 5, wherein only one of the phase-shifted incremental signals is illustrated in FIG. 5. In the detected scanning signals, the high-frequency signal portion represents the high-resolution incremental signal with the signal period SP_{INC}, while in the area of the reference marking field a disturbance is superimposed on the scanning signal at the reference position x_{REF}, which can be extracted from the scanning signal for generating a high-resolution reference pulse signal. This will be explained in detail in what follows.

[0055] Therefore the effect of the reference marking field on the scale because of the steps in accordance with the present invention only appears in a very limited spatial range in the resulting scanning signal. Initially, this range is determined by the dimensions of the reference marking field. In this connection so-called chirped graduation structures, such as will be described in the following description, are particularly advantageous. They make substantially narrower ranges possible, in which a reference pulse signal can be detected. Ranges of 40 µm can be typically achieved if the above mentioned orders of magnitude for the various graduation periods, etc., are maintained. It is therefore possible in spite of a clearly greater extension of the reference marking field on the scale to generate a reference pulse signal of little width, i.e. with a very large spatial resolution. The high resolution which can be achieved in the generation of the reference pulse signal permits synchronization in particular with the also high-resolution incremental signals.

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[0056] In order to additionally assure sufficient insensitivity toward possible tilting of the scanning unit with respect to the scale in the course of the employment of the position measuring system of the present invention, it has furthermore been shown to be advantageous if the size of the reference marking field is selected to be such that it approximately corresponds to the size of the cross section of the beam emitted by the light source.

[0057] In what follows, an explanation will be provided by FIGS. 6 and 7a to 7e how the generation in accordance with the present invention of a high-resolution reference pulse signal from the resulting scanning signals takes place.

[0058] To this end, a greatly schematized block circuit diagram is represented in FIG. 6 for explaining the signal processing taking place following the generation of the scanning signals A, B, C in the scanning unit. Strictly speaking, FIG. 6 does not represent a signal processing arrangement, instead it is used for explaining the algorithm by which the high-resolution reference pulse information is generated in accordance with the present invention. It is therefore not necessary that the various function blocks and function units be embodied as hardware. Basically it is most advantageous if signal processing, such as will be explained in what follows, is performed in a digital computer device in the form of ASICs, FPGAs and/or signal processors.

[0059] The scanning signals A, B, C which, in the present case are phase-shifted by 120°, are initially conducted to a transformation unit 34, in which these signals A, B, C are converted in a known manner into two incremental signals S_0, S_{90}, which are phase- shifted by 90° and have an imposed disturbance in the area of the reference position x_{REF}, as explained above.

[0060] Before addressing the further function blocks in detail within the framework of the performed signal processing in what follows, first the basic principle of the generation in accordance with the present invention of high-resolution reference pulse information from the generated scanning signals will be explained. A multi-step process for the extraction or generation of this information is essentially provided in this connection. Within the scope of the signal processing taking place, first evaluation device 40 is provided, which is suitable for the determination of a rough reference position $x_{REF,G}$ from the maximum of the resultant disturbance in the

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scanning signals at a defined relative position of the scale 10 and the scanning unit 20. Moreover, a second evaluation device 50 is required, which is suitable for the determination of a beat signal phase from the difference between a whole-number multiple of the reference pulse signal phase and a whole-number multiple of the incremental signal phase. Furthermore, a third evaluation device 60 is provided, which is located downstream of the first and second evaluation devices 40, 50 and is suitable to unequivocally mark a beat signal period from the rough reference position $x_{REF,G}$ and to emit a signal or information in regard to a fine reference position $x_{REF,F}$ from the beat signal phase if a defined phase position exists.

[0061] The further processing of the phase-shifted incremental signals S_0, S_{90} via the various function blocks within the scope of the signal processing taking place will now be explained in detail in what follows.

[0062] First, the incremental signals S_0, S_{90} are conducted to an interpolator and counting unit 32, which processes these signal in a known manner. This means that the incremental signals are divided and the interpolated signals are provided to a counter. Accordingly, a high-resolution signal S1 regarding the respective incremental position results at the output of the unit 32. The chronological course of the respective signal in the case of an even movement of the scale in relation to the scanning unit is represented in FIG. 7a. This disturbance cannot be detected in the representation in FIG. 7a because of the slight disturbance with the scanning signals by the reference marking, i.e. in accordance with the representation in FIG. 7a the result is a linear increase of the incremental position (ordinate: y-axis) over time (abscissa : x-axis).

[0063] Thereafter the signal S1 is conducted in a first processing branch to a filter 33, which is embodied as a band pass filter, which filters the frequency portions of the incremental signals out of the signal S1. Therefore the filter 33 constitutes a blockage in the frequency range of the incremental signal frequency f_{INC}. A corresponding filtered signal S2, which is substantially caused by the effect of the mean reference pulse signal period $SP_{REF, m}$, is represented in FIG. 7b.

[0064] Information regarding the amplitude or phase of the filtered signal S2 is subsequently further used in the form of the two signals S3 or S4. The signals S3 or S4 are represented in FIGS. 7c and 7d.

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[0065] The signal S3 regarding the reference pulse signal amplitude is then conducted to a maximum detector 41, by which the amplitude maximum of the signal S3 is determined. The amplitude maximum determined in this way marks the rough reference position $x_{REF,G}$, i.e. information, or a signal S5 regarding a rough reference position $x_{REF,G}$ is present at the output of the maximum detectors 41 and will subsequently be processed further. Incidentally, in the above used terminology the maximum detector 41 represents the first evaluation device, which is identified in the drawings as a function block with the reference symbol 40.

[0066] The signal S1 resulting at the output of the interpolator and counting unit 32 is furthermore also conducted as a signal regarding the incremental signal phase to a function block with the reference symbol 50, which substantially represents the above mentioned second evaluation device. The signal S4 regarding the reference pulse signal phase at the output of the filter 32 is furthermore conducted to the second evaluation device 50. On the part of the second evaluation device 50, the multiplication of the respective input signals with the whole-number factors N_{RI} or N_{INC} is performed at the input by the multiplication units 51 and 52. Accordingly, respective signals S6, S7 regarding whole- number multiples of the reference pulse signal phase or the incremental signal phase are present at the output of the multiplication units 51, 52. On the part of the second evaluation device 50, the signals S6, S7 are finally conducted to the inputs of a difference-forming unit 53. Following the forming of a difference, a signal S8 regarding a beat signal phase φ_s is present at the output of the difference-forming unit 53, and therefore at the output of the second evaluation device 50.

[0067] Subsequently the signals S5, S8 regarding the rough reference position $x_{REF,G}$ and regarding the beat signal phase φ_s resulting at the outputs of the first and second evaluation devices 40, 50 are conducted to a function block with the reference symbol 60, which substantially represents the third evaluation device also already mentioned above.

[0068] The third evaluation device here includes a difference- forming unit 62, in which a subtraction of a fixed, selectable nominal phase value $\varphi_{Nominal}$ from the beat signal phase φ_s, or the signal S8 takes place. A signal S10 regarding a beat signal phase difference results at the output of the difference-forming unit 62. The signal

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S10 regarding the beat signal phase difference has the typical saw-tooth-like signal course of phase signals - similar to FIG. 7e - and has zero points with the distance of the beat period.

[0069] The same as the signal S5 regarding the rough reference position $x_{REF,G}$, the signal S10 is supplied to a selection device 61 which is also a component of the third evaluation device 60. Via the selection device 61 the particular crossover of the beat signal phase difference is determined which lies within the same beat period as the rough reference position $x_{REF,G}$. The crossover selected in this manner is output as the signal S11 and defines the fine reference position $x_{REF,F}$.

[0070] Subsequently, in case there is a fine reference position $x_{REF,F}$, a downstream arranged memory 34 is addressed by the signal S11 emitted via the output of the third evaluation device 60. Parallel with the signal S11, this memory 34 is continuously supplied with the value of the signal S1, i.e. the high-resolution position information available at the output of the interpolator and counting unit 32. In case there is a fine reference position $x_{REF,F}$, this position information, i.e. S1, is written, controlled by the signal S11, into the memory 34. This position information will be called the reference pulse offset in what follows.

[0071] Thus, the determination of a reference pulse information is performed with the same resolution as the incremental measurement. As a result, a signal S12 which contains the information regarding the fine reference position $x_{REF,F}$ of the desired high resolution is present at the output of the memory 34.

[0072] Regarding the concrete use of this information, or of this signal S12, there are various options which, in connection with the processing of reference pulse information, are basically known and are therefore only schematically indicated in the representation of FIG. 6. One the one hand, it is possible via the indicated output 35 to directly output the determined reference pulse offset for further processing. Alternatively it would be possible to provide a subtractor 36, also only schematically indicated, for subtracting the determined reference pulse offset from the incremental position.

[0073] Of course alternative embodiments can also be realized within the scope of the present invention besides the embodiment variation so far explained. In this case

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various variations can be employed in particular in regard to the scanning beam path used for generating the scanning signals.

[0074] Thus, the reference marking field on the scale could also be differently designed than it was explained in the above example. It is in particular possible to provide that not only a single further reference marking graduation period $TPM_{REF,m}$ is contained in the reference marking field besides the incremental graduation period TPM_{INC}, but instead a spectrum of further reference marking graduation periods TPM_{REF}, which are distributed as a function of location around the mean reference marking graduation period $TPM_{REF,m}$. In such a case the scanning plate, or the corresponding scanning graduations, can be correspondingly embodied. This then also contains a spectrum of reference scanning grating graduation periods TPA_{REF}, which are distributed around a mean reference scanning grating graduation period $TPA_{REF,m}$ and are appropriately matched to the reference marking graduation period $TPM_{REF,m}$. Such an embodiment of the reference marking field can take place, for example, in that the respective graduation structures in the reference marking field, as well as in the reference scanning grating, are designed as so-called chirped graduation structures, within which the respective graduation periods are evenly and continuously changed along the measuring direction x. The ratio V of the existing frequency width Δf of the spectrum of grating frequencies to the mean reference marking frequency $f_{REF,m} = 1/TPM_{REF,m}$ here determines the width of the disturbance with the resultant scanning signal. This ratio $V = \Delta f/f_{REF,m}$ advantageously lies in the range between 0.001 and 0.5.

[0075] It would moreover be possible to design the scanning plate as a Fresnel lens, which advantageously reflects the graduation structure of the scale back to the scale. Such a Fresnel lens can be arranged symmetrically (on axis), as well as asymmetrically (off axis) with respect to the optical axis of the scanning beam path.

[0076] In the case of a scale design in accordance with FIG. 2 it is furthermore possible to provide only a single scanning graduation on the scanning side, or respectively on the scanning plate, i.e. not to provide spatially separated partial areas which respectively function as incremental scanning gratings and reference scanning gratings, but instead to realize the respectively necessary deflection effects by a single scanning graduation. To this end, at least the required reference scanning grating

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graduation period $TPAG_{REF}$ and the incremental graduation period $TPAG_{INC}$ are contained in the corresponding scanning graduation, which then cause a deflection of the beams impinging from the various spatial directions in the direction toward the scale. This embodiment variation of the scanning side has been shown to be useful in particular in the case where the scanning plate is arranged very close to the scale, so that therefore no complete spatial separation of the split partial beams from the reference marking field exists, such as was the case in the example explained in FIG. 1, for example.

[0077]   Besides the exemplary embodiments described, it is understood that alternative variants also exist within the scope of the present invention.